Retinex Scheme — RS Image Enhancement

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Abstract—As remote sensing images can be used to identify features and interpret ground conditions, they have been widely used in many fields from environment resources investigation to military operation. However, most of the remote sensing images have little visual contrast and poor resolution. Thus, the remote sensing image enhancement technique is almost always applied before the remote sensing images are analyzed. Numerous image enhancement techniques are available. In this study, a novel image enhancement technique, Multi-scale Retinex (MSR), is introduced. This enhancement technique is effective especially for images with poor visibility or low resolution. In this study, several classic image enhancement techniques, say, histogram equalization, are also introduced. To illustrate the effectiveness and superiority of the MSR technique on remote sensing image enhancement, the technique is compared with these classic enhancement techniques by enhancing a remote sensing image with poor visibility and little visual contrast. The results show that MSR technique is satisfying and superior over the other enhancement techniques.

Keywords—Remote sensing image; Image enhancement; MSR; Poor visibility; Visual contrast

I. INTRODUCTION

Remote sensing sensor systems detect reflected or emitted radiation from features on the earth's surface. Usually, the detected energy does not fill the entire gray level range the sensor is capable of. So, most of the remote sensing images have little visual contrast and poor resolution. Therefore, remote sensing image enhancement occupies a peculiar position in remote sensing image processing and is an important preprocessing step for subsequent analysis. By now, numerous image enhancement techniques have been proposed. One way to enhance the remote sensing image is to redistribute the image gray levels to fill the entire range of the display medium. There are linear and non-linear contrast enhancement techniques. However the effectiveness of these techniques is very limited. Another classic enhancement technique is histogram equalization. This technique works well for most of the images, but not so well for images with very dark and very bright areas at the same time. In this study, the MSR algorithm is introduced to solve this problem and enhance the remote sensing image effectively.

The idea of the retinex was conceived by Edwin Land[1] as a model of the lightness and color perception of the human vision. Through the years, Land[2][3] evolved the concept from a random walk computation to its last form as a center/surround spatially opponent operation which is related to the neurophysiological functions of individual neurons in the primate retina, lateral geniculate nucleus, and cerebral cortex. Subsequently Hurlbert[4][5] studied the properties of this form of retinex and other lightness theories and found a common mathematical foundation, which possesses some excellent properties but cannot actually compute reflectance for arbitrary scenes. Basic study of the properties of the center/surround retinex led us in the direction of using Gaussian surround used by Hurlbert as opposed to the exponential surround used by Moore [6] for analog VLSI resistive networks. Based on this idea the Single-scale Retinex (SSR) is developed and subsequently the Multi-scale Retinex (MSR) is developed by Jobson, et al[7][8].

In the course of our experiments, this technique is compared with several other image enhancement techniques to demonstrate its usefulness and effectiveness for enhancing remote sensing images.

II. IMAGE ENHANCEMENT TECHNIQUES

2.1 Linear Stretch

One of the most common methods of enhancing an image is the application of a linear stretch technique to stretch the dynamic range of the image. This is a linear operation and matches the image's dynamic range to the dynamic range of the display medium. Thus, it allows for a greater contrast between features and can lead to a more accurate interpretation of features within the image. However, it has limited success on scenes that encompass a much wider dynamic range than that can be displayed. In this case, loss of detail occurs due to saturation and clipping as well as due to poor visibility in dark regions of the image. For an image with dynamic range between $r_{\min}$ and $r_{\max}$, and a display medium with dynamic range $d_{\max}$, this transform can be represented by

$$I'(x,y) = \frac{d_{\max}}{r_{\max} - r_{\min}} \cdot \left[I(x,y) - r_{\min} \right] \quad (1)$$

where $I(x,y)$ denotes the intensity of the original image, and $I'(x,y)$ denotes the intensity of the enhanced image. This

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particular transform will transform the image to completely fill the dynamic medium. This does not imply, however, that this process will provide a good visual representation of the original image. The modification of the histogram distribution is used to illustrate the effect of this technique, see Fig.1 (a).

2.2 Non-linear Transform

Another well-known method used for providing dynamic range compression or stretch is the application of non-linear transforms, such as the gamma non-linearity, the logarithm function, and the power-law function, to the original image. These functions are typically biased toward increasing the 'visibility' in the 'dark' regions by sacrificing the visibility in the 'bright' areas. The output of such filters can be described by

$$I^{'}(x,y)=T\left[I(x,y)\right] \tag{2}$$

where $T\left[\cdot\right]$ represents the non-linear transform. A typical non-linear transform is

$$I^{'}(x,y)=I(x,y)^{\log(a)/\log(0.5)} \tag{3}$$

where a denotes a parameter used to control the transform function, $I(x,y)$ denotes the *intensity of* the original image, and $I^{'}(x,y)$ denotes the intensity of the enhanced image. The transform curves with different a values are shown in Fig.1 (b).

2.3 Histogram Equalization

A global technique that works well for a wide variety of images is histogram equalization. This technique is based on the idea of remapping the histogram of the scene to a histogram that has a near-uniform probability density function. This results in reassigning dark regions to brighter values and bright regions to dark values. Histogram equalization works well for scenes that have unimodal or weakly bi-modal histograms, but not so well for those images with strongly bi-modal histograms. The modification of the histogram distribution is used to illustrate the effect of this technique, see Fig.1 (c).

2.4 Multi-scale Retinex

The single-scale retinex (SSR) is given by

$$R(x,y)=\log I(x,y)-\log\left[F(x,y)*I(x,y)\right] \tag{4}$$

where $R(x,y)$ is the retinex output, $I(x,y)$ is the image to be enhanced, "*" denotes the convolution operation, and $F(x,y)$ is the surround function,

$$F(x,y)=K\exp\left[-(x^2+y^2)/\sigma^2\right] \tag{5}$$

where σ is the Gaussian surround space constant, or the scale, and K is selected such that

$$\iint F(x,y)dxdy=1 \tag{6}$$

The MSR output is simply the weighted sum of the outputs of several SSRs with different scales.

Mathematically,

$$R_M(x,y)=\sum_{n=1}^{N} w_n\cdot\left\{\log\left[I(x,y)\right]-\log\left[I(x,y)*F_n(x,y)\right]\right\} \tag{7}$$

where N is the number of scales and $I(x,y)$ is the input image, $R_M(x,y)$ is the output of the MSR process, $F_n(x,y)$ represents the nth surround function, w_n are the weights associated with $F_n(x,y)$, and "*" represents the convolution operator. The surround functions $F_n(x,y)$ are given as:

$$F_n(x,y)=K_n\exp\left[-(x^2+y^2)/\sigma_n^2\right] \tag{8}$$

where σ_n is the standard deviation of the nth surround function, and K_n is selected such that:

$$\iint K_n\exp\left[-(x^2+y^2)/\sigma_n^2\right]dxdy=1 \tag{9}$$

The MSR is superior obviously to the SSR in combination of scales[9], which provide both dynamic range adjustment and tonal rendition at the same time. For color images, every spectral band of the color image should be applied to the techniques.

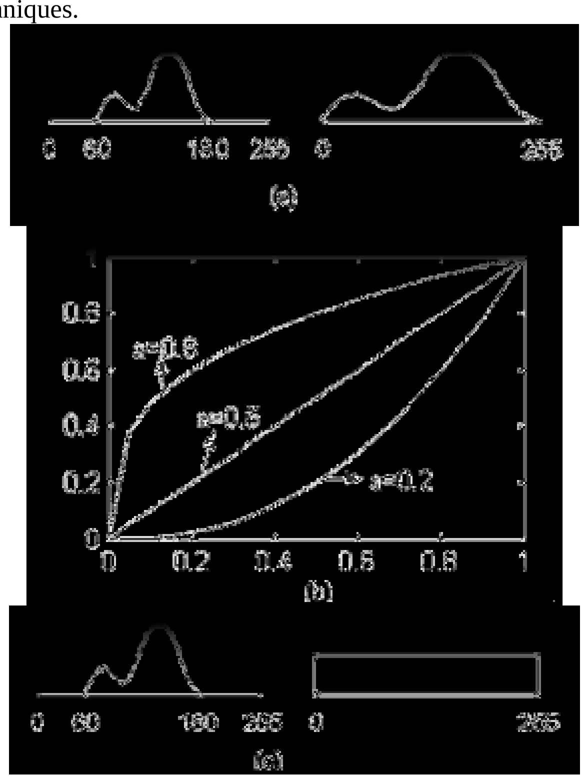

Fig 1. The characteristics of the enhancement techniques. (a) The modification of the histogram distribution when using linear stretch. (b) The transform curves with different a values when using non-linear transform. (c) The modification of the histogram distribution when using histogram equalization.

III. MSR IMPLEMENT

As stated above, the MSR is implemented using convolution operation and performing this operation in the spatial domain is extremely time-consuming. In order to make the MSR technique a real-time technique, the convolution theorem is used to convert the convolution operation in spatial domain to multiplication in the spatial-frequency domain[10][11]

$$f(x,y) * g(x,y) \Leftrightarrow F(\mu,\nu)G(\mu,\nu) \qquad (10)$$

where $F(\mu,\nu)$ and $G(\mu,\nu)$ are the spatial frequency domain representations of $f(x,y)$ and $g(x,y)$ respectively. The author employs the 2-dimensional $M \times N$ forward and inverse Discrete Fourier Transforms (DFT)[11]

$$F(\mu,\nu) = \frac{1}{MN}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1} f(x,y)\exp\left[-j2\pi(\mu x/M + \nu y/N)\right] \qquad (11)$$

$$f(x,y) = \sum_{\mu=0}^{M-1}\sum_{\nu=0}^{N-1} F(\mu,\nu)\exp\left[j2\pi(\mu x/M + \nu y/N)\right] \qquad (12)$$

Then the MSR can be rewritten as

$$R_M(x,y) = \sum_{n=1}^{N} w_n \cdot \left\{\log\left[I(x,y)\right] - \log\left[F^{-1}(I^{'}(\mu,\nu)F_n^{'}(\mu,\nu))\right]\right\} \qquad (13)$$

where $I^{'}(\mu,\nu)$ and $F_n^{'}(\mu,\nu)$ represent the DFTs of $I(x,y)$ and $F_n(x,y)$ respectively, and F^{-1} represents the inverse DFT. The DFT can be computed with Fast Fourier Transform (FFT), and the 2-dimensional transforms can be computed by applying 1-dimensional FFTs to the rows and columns of the image.

IV. EXPERIMENTAL RESULTS

Although the techniques introduced in this study can be used to enhance images, as discussed above, the MSR technique is more suitable for enhancing remote sensing images. To demonstrate the effectiveness of the MSR technique and its superiority over the other techniques on enhancing remote sensing images, a remote sensing image enhancement experiment is conducted using these enhancement techniques respectively. The original image (Fig.2 (a)) is a typical remote sensing image with poor visibility and little visual contrast. Fig.2 (b), Fig.2 (c), Fig.2 (d) and Fig.2 (e) are the enhanced images from linear stretch, non-linear transform, histogram equalization and MSR respectively. The experiment demonstrates that the effectiveness of the non-linear transform is very limited, the linear stretch enhance the image but not good enough, the histogram equalization improve the visibility in the dark areas with the cost of low visual contrast in the bright areas, and the MSR yields a satisfying enhanced image.

V. CONCLUSIONS AND DISCUSSIONS

In this research, the remote sensing image enhancement is discussed and several enhancement techniques are introduced. However, most of the remote sensing images always have poor visual contrast and poor resolution. Therefore, some of the enhancement techniques may lose their competence for enhancing this kind of images. According to the characteristics of the remote sensing images, the MSR technique is introduced. And the effectiveness and its superiority over other techniques are also demonstrated by an experiment.

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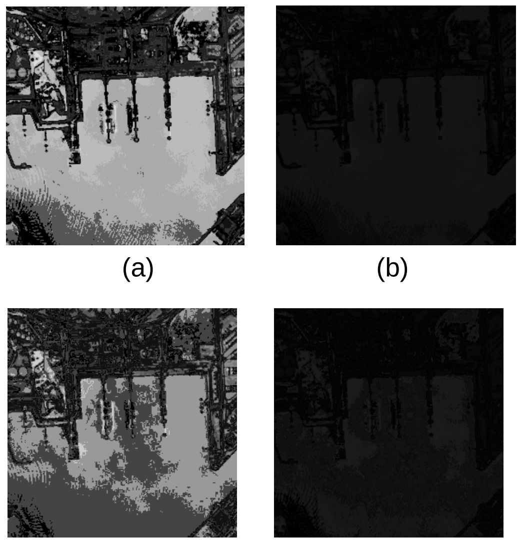

(a) (b)

(c) (d)

(e)

Fig 2. Remote sensing image enhancement using the enhancement techniques introduced in this study. (a) The original remote sensing image. (b) The enhanced image from linear stretch. (c) The enhanced image from non-linear transform. (d) The enhanced image from histogram equalization. (e) The enhanced image from MSR.